An App-based Algorithmic Approach for Harvesting Local and Renewable Energy Using Electric Vehicles

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Abstract: The emergence of electric vehicles (EVs), combined with the rise of renewable energy production capacities, will strongly impact the way electricity is produced, distributed and consumed in the very near future. This position paper focuses on the problem of optimizing charging strategies for a fleet of EVs in the context where a significant amount of electricity is generated by (distributed) renewable energy. It exposes how a mobile application may offer an efficient solution for addressing this problem. This app can play two main roles. Firstly, it would incite and help people to play a more active role in the energy sector by allowing photovoltaic (PV) panel owners to sell their electrical production directly to consumers, here the EVs' agents. Secondly, it would help distribution system operators (DSOs) or transmission system operators (TSOs) to modulate more efficiently the load by allowing them to influence EV charging behaviour in real time. Finally, the present paper advocates for the introduction of a two-sided market-type model between EV drivers and electricity producers.

1 INTRODUCTION

The past decade has seen a steep rise in the development of renewable energy production capacities, mainly driven by the willingness to (i) reduce pollution and greenhouse gas emissions and (ii) limit the dependency on fossil fuels. In addition, electric vehicles (EVs) are now emerging rapidly. The conjunction of these factors may be an opportunity to set the basis of a joint optimization approach for charging EVs with regard to the fluctuation of renewable energy production. This has already been the topic of academic research in the past decade (see (Palensky et al., 2013) for a comprehensive review). In particular, it has been shown that EVs may be efficiently used in order to balance the load within distribution networks (Caramanis and Foster, 2009). Also, vehicle charging can be influenced by dynamically adapting tariffs as shown in (O'Connell et al., 2011). Even though these results are of significant importance, none of them propose a convenient way to apply them to real situations.

In this paper, we focus on the problem of optimizing the charge of a fleet of EVs in a context where it is important to match, at best, local energy consumption and renewable electricity production. We argue that a mobile application would be an efficient and elegant support to deploy algorithms to dispatch EVs to electricity sources. In Section 2, we first explain how this app should be designed. In Section 3, we describe a few problems that may be efficiently addressed by adhoc algorithms integrated into the app. Section 4 lists a few generic algorithmic techniques that could be used for addressing decision-making problems within the app. Finally, Section 5 concludes.

2 MOBILE APPLICATION DESCRIPTION

The combination of (mobile) EVs and (static) electricity sources is seen as a multi-agent system, where mobile agents (the EVs) should gather, at best, renewable energy under travel distances and electricity production fluctuations constraints. On the one hand, electricity sources are static, but electricity production is fluctuating, depending on solar irradiation or wind speed. On the other hand, EVs are mobile, but are subject to travel constraints.

One main objective is to allocate electricity sources to EVs based on geographical parameters (starting point, destination, etc.). A second aspect is to take into account the fact that several EVs may compete for the same electricity source. So, it appears that the fleet of should be coordinated in order to attain a consensus so that the amount of electricity harvested by the whole fleet of EVs is maximized. In addition to this, one should take into account the fact that a specific subclass of sources of electricity may be used to rapidly charge EVs, thus offering the opportunity to make a stop when travelling, or even to take a small detour, in order to get to a fast-charging station.

The app should be an efficient tool for reaching such a consensus among the static and dynamic agents. To this end, we suggest building an app in the form of a two-sided market platform.

2.1 Two-sided Market

One main role of the app is to create a convenient way for PV panel owners to share (and sell) their electricity to EV drivers. This is particularly important, since the electrical network has not been designed to absorb electricity production from private dwellings. For example, during solar production peaks, PV panels may have to be disconnected because of overvoltages on the network (see e.g., (Olivier et al., 2016)). Neither has the electric network been designed to supply a sufficient amount of power sufficient to fully recharge a large fleet of EVs in a few hours within a neighbourhood.

Consequently, on one side we have PV panels owners that may want to find a way to profitably exploit their installation, and on the other side we have EV drivers who may be constrained to charge their vehicles while they are occupied by other tasks. The app is aimed at satisfying both requirements and to make it easy for each sides' to benefit from the other needs.

2.2 Driver Services

To be successful, the app must be attractive to EV drivers. For this purpose, a booking service will be provided to guarantee a charge level for the drivers. Moreover, the app intelligence should be able to propose a flexible and suitable choice of charging points depending on the user needs.

One way for the app to output convenient charging point suggestions would be to specify journeys using a set of geographical points. The simplest case would be to specify the starting point (A) and the destination (B). In this configuration, the app would compute the optimal stations at which the driver should stop as they travel from A to B, knowing the level of charge, consumption and battery autonomy of the vehicle. A more-advanced case would be to specify three geographical points: the starting point (A), a stop (B) and a final destination (C), as well as the time duration spent at location B, where it may be possible to recharge the EV. Taking all these parameters into account, plus eventually additional constraints that the drivers may have, it would suggest the best stations for drivers where they should stop during the journey. Obviously, suggestions should also be optimized in order to minimize energy costs and/or curtailment. As the app interacts with a fleet of EVs and not just one single EV, it may also be interesting to optimize charging station suggestions globally rather than on a single EV basis. This would lead to a better solution at the level of an EV fleet but may penalize some EV owners due to a possible lack of fairness of the global solution. This fairness issue could be addressed by implementing a compensation mechanism. It could consist in monetary terms, but also in other advantages like free charge or booking priority.

2.3 Producer Services

Producers can be divided into two categories: companies and individuals. Companies can either be large renewable energy source owners, DSOs or substantial charging-point owners, whereas the individuals consist mainly of private owners of PV units, with a nominal power less than 10 kWp, and who also want to sell the electricity they produce.

We may reasonably assume that, in many cases, EV users may want to book a charging station, through the app, that has a significant charging power (e.g., higher than 20 kW). This may penalize individual charging stations, which, if they want to sell their green electricity, are limited to the power produced by their PV installation. However, we can reasonably assume that in the coming years, with the rise of batteries, these individual producers should be able to store their excess of green electricity. In such a context, during certain periods of the day, they could offer a charging power close to the power of the PV installation plus the power that their batteries can deliver. Indeed, with a 10 kWp PV installation, an individual producer will not be able to sell many green charges per week due to the rather limited amount of energy that such an installation can produce. Indeed, if we assume a load factor of 8.9% for the PV installation, the average European load factor for PV (Energy - Yearly statistics 2008 (Eurostat)), the 10 kWp PV installation would produce on a daily basis $10 \times 0.089 \times 24 = 21.36$ kWh. So, at most, only once every three days, the individual producer will be able to sell a full fast charge to an EV with a 60 kWh battery. This illustrates why individual charging may have a low level of availability.

The app could offer many services to the owners of the charging stations. It would include a booking system, but also other services based, for example, on data to manage prices and attractiveness of the charging points. More specifically, the app could allow for the efficient retrieval of data about those stations (such as price, power, etc.). From these data, it would be able to carry out an analysis in order to establish how pricing can influence the attractiveness of charging points. Based on such an analysis, the app could also help the producers to better manage their charging stations, by having, for example, dynamic pricing to adapt demand to production. It could also help individual users to manage their batteries and the flexible loads that they may have at home (e.g., washing machine, heat pump, etc.).

3 SUPPORTED UNDERLYING PROBLEMS

In addition to creating a two-sided market, a mobile application could also provide a set of services for addressing underlying problems associated with EV charging and network management. We believe that the opportunity to solve these problems via the app may be a game changer in the electricity sector, mainly due to the app's ability to enable producers and consumers react quickly and in a very flexible way.

3.1 Booking Service

In the short-term, congestion problems are going to occur close to well-located charging points as a full recharge typically takes at least 30 minutes with superchargers, and more generally many hours with classic chargers. As a result, we can expect that knowing in advance whether a charging station will be available or not may probably become one of the main problems for EV drivers. For now, no suitable solution to address this problem has emerged, although most EV drivers have already experienced this inconvenience.

The app's booking service would be a solution to this problem, and it should work as follow: Firstly, stations will only be bookable a short period in advance (say, for example, 24 hours), and this for several reasons. For example, if someone could book a station for an entire year, this would lead to a lack of attractiveness of the app for new users. As another example: the app intelligence will be responsible for organizing a fair distribution of charging stations among users to avoid the same type of problem. Indeed, we want to avoid situations where far-sighted users would always book the most attractive stations, at the expense of other users. Actually, two main reasons motivate this proposal: on the one hand, the app must remain attractive by providing each type of user with a good suggestion, while on the other hand, one of the main goals of the app is to retain and maintain as much flexibility as possible in the demand for electricity.

We propose two solutions to maintain flexibility of the demand while allowing charging station booking:

- The first solution is to adapt electricity pricing. By booking a charging station suggested by the app just prior to stopping to charge their EV, the driver is more likely to offer a valuable flexibility service to the network (provided that the app is smart enough) that should be rewarded, for instance, with a reduction in the cost of the charge. On the other side of the coin, the early booking driver puts advance constraints in advance on the network that may not match renewables production (corresponding to the situation where the bid is too early compared, for example, to the the time horizon at which it is possible to get accurate predictions of renewable production). Thus such a user would have to pay an additional fee for an early booking. It is important to note that the frontier between early and late booking is not clearly defined a priori. However, one could imagine designing learning algorithms that are able to classify users' behaviour according to the service they are actually offering to the network.
- In the second solution, the booking transactions could be stored in blocks, which would only be accepted after a certain time, thus allowing more flexibility in terms of charging station allocation. This solution could be based on distributed ledgers (such as blockchain technology (Nakamoto, 2008)) associated with smart contracts[1] which could be used to determine the con-

[1]Smart contracts (also called self-executing contracts, blockchain contracts, or digital contracts) are simply computer programs that act as agreements where the terms of the agreement can be coded in advance with the ability to self-execute and self-enforce themselves. This code defines the rules and consequences in the same way that a traditional legal document would, stating the obligations, benefits and penalties which may be due to either party in various different circumstances. This code can then be automatically executed by a distributed ledger system.

ditions of the transactions without passing by a third party, so adding more dynamism and autonomy to the app.

Finally, a problem which rapidly comes to mind when proposing the idea of a global booking service is the difficulty to control whether bookings are respected. Indeed, unless you own every single station that you propose to drivers, you cannot guarantee that a station booked by one driver will not be occupied by another driver that is not using the app. The solution we propose amounts to creating a global booking service, which would not be part of the one single app, but should also be available for other app creators. It would retain all the booking data about each station. Station owners would just have to rely on this tool to manage the booking around their stations. The tool could probably have some specific features and propose some additional services but this is not the subject we want to explore here.

3.2 Demand Management and Dynamic Pricing

Managing the demand is probably one of the best assets of the app. By maintaining a certain degree of flexibility in booking, the app allows to better correlate local consumption with production by making EVs charge close to energy sources. As shown in (O'Connell et al., 2011), a dynamic pricing system could allow the app to boost the demand in order to follow, more closely, the production. Moreover, with smart chargers (i.e. chargers that may automatically change the amount of power they output) and accurate weather forecasting, we can hope to fit, exactly, the (over)production to the EV charging by allocating each vehicle to an appropriate station for a precise duration of time.

To allow for such a load management, a convenient dynamic pricing system must be implemented. It therefore has to allow producers to keep a hand on the demand simply by raising or lowering charging prices. For instance, they could lower prices at overproduction times to increase demand and do the opposite when domestic consumption is peaking, or when the level of renewable energy production is low. This will all be done through the app that should help charging point owners to understand the influence of these pricing choices. For instance, the app could provide estimations of the demand as a function of the price chosen for one charging point.

3.3 Data Mining

Another strength of the app is the flow of data passing through it and that can be stored. These data consist mainly of information about drivers trips (travel time, distance, ...) or the performance of EVs (mean consumption, charge level variations, ...). More generally, we can summarize this information as when, where, and at which frequency EV drivers charge their cars and how it influences the vehicles' performances, the vehicles' fleet dynamics, and the network load. This information may be of interest to a number of actors in the automotive and energy industries. Here is a short list of such interested actors, as well as of their potential use of the app's data:

- **Drivers:** The drivers themselves would be the first to benefit from these data through a self-learning improvement of the app's dispatching strategy based on previous results.
- **Car manufacturers:** More practically, EV real-time performances could help manufacturers identify key points for future improvements.
- **Producers:** Forecast of the density of traffic at different locations, at different times could help producers apply an appropriate dynamic pricing strategy.
- **Electricity Networks:** These same forecasts, combined to renewable energy production predictions, can be used by TSOs/DSOs to find methods to balance the load and prevent overloads/overvoltages. Dynamic pricing can be used in two different schemes: (i) it can influence the time at which EV users decide to charge their cars, or (ii) it can be used to orientate the EV users to the right charging station where they would not cause any problems, or even be beneficial to the network.

3.4 Shared Economy Model

EV drivers can already use a panel of apps helping them to find information about charging stations that they could possibly use (PlugShare®, ChargeBump®, NextCharge®). However, all of them work with a one-view driver-oriented system. An advantage of our app would be its multi-view organization aiming to be profitable for every actors involved. This approach, supported by a shared economy model, would benefit drivers by optimizing their travel and charging time, and also the producers by allowing them to implement dynamic pricing methods to modulate the attractiveness of their products.

In addition, shared economy models are becoming more and more popular and are reaching every branch of capitalism, as stated in (Rifkin, 2014). The success of Uber® or Airbnb® prove that people are eager for a change of economic model. Adequacy of supply and demand, efficiency, affordability and scalability are all different reasons why these models are so successful and are all properties that would be beneficial for an EV driver app. As a matter of fact, it would seem more convenient nowadays to directly book a station to its owner than having to solicit the intervention of an external organization.

3.5 Reactivity

To work properly, all the solutions proposed have to be extremely reactive. Nowadays, as the number of EVs and charging stations increases, there is a growing need for a real-time information platform. Mobile applications currently offer one of the most reactive platforms and a true answer to this kind of problems. In particular, the booking can be easily and dynamically managed by connecting together a series of drivers' and producers's phones. More than connecting people, it would also offer a direct connection to smart electric cars, instantly collecting immediately all the data needed to predict when and where the next charge should be done. Moreover, the app would open the door to more connected payment methods like virtual money or phone payment which would add some more fluidity to the system.

Finally, a mobile application adds a layer of reactivity over all these features due to its proximity to people. More than 2 billion people have a smartphone[2]. Therefore, apps are always with us allowing them to inform us of any important update like price modifications, overproduction risks or reservation problems directly when they happen so that we can react in a minimum amount of time.

4 ALGORITHMIC SOLUTIONS

As showed in previous sections, a mobile application could work as a good support to implement efficient EV charging, while favouring the integration of renewables into electricity networks. Nevertheless, as pointed out previously, a series of algorithms is necessary to achieve this implementation. In the following, we describe a few possibilities for designing them.

[2]According to the website statista.com: http://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/

4.1 Discrete Optimization and Machine Learning

Dispatching EVs to a set of charging points while minimizing certain constraints for the user (e.g. costs, detour time) and/or for the network (e.g. amount of energy curtailed) can be modelled as a discrete optimization problem. A possible solution is therefore to use graph theory and algorithms, such as the minimum spanning tree-type algorithms, where the nodes represent either a charging point or a driver destination, while the weights of the edges are equivalent to the constraints of the problem. Meta-heuristics, such as genetic algorithms, have also proven to be useful in the resolution of this kind of problems.

Pricing decisions is another important aspect of the problem these should take into account not only the variability of renewable energy but also the behaviour of the different actors. This could typically be solved with some machine learning algorithms.

4.2 Multi-agent systems

A last generic domain that is also closely related to our problematic is, of course, the one of multi-agents systems. Multi-agent technology has already been used in power networks, leading, for example, to ways to reduce imbalances in distribution networks (Kok et al., 2008) or to manage congestions caused by electric vehicles in a distribution grid (Hu et al., 2015). Matching this technology with our mobile application could probably enhance its performances.

5 CONCLUSION AND FUTURE WORKS

This article shows how a mobile application (app) may be an appropriate support for tackling several upcoming obstacles associated with the rise of EVs and renewable energy production capacities, combined with the management of the electrical network load. This app may be seen as an interface between drivers and producers, providing services to both of them. This paper also lists a series of algorithms that could be used in this app to solve several decision-making issues related to this app.

The main purpose of this paper is to make the public aware that the upcoming issues regarding EV charging and network management could be solved by using an app-based strategy. Several research directions should be taken for accelerating the development of such an app. They should encompass algorithmic research for tackling all the decision-making issues related to this app. They should also relate to all the more “practical aspects” to be put in place for such an app to be successful (e.g., design of the right user interface, data management issues, etc.).

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